Using Satellite Simulators to Diagnose Clouds in Climate Models

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CERES Science Team Meeting

October 4-6, 2011

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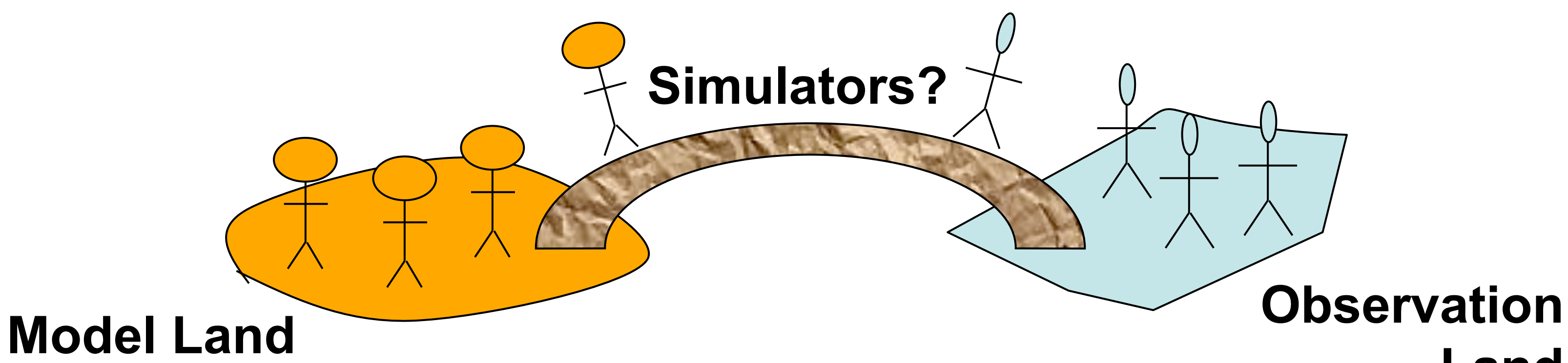
PCMDI

Program for Climate Model Diagnosis and Intercomparison

Outline

- What is a "satellite simulator" and why is it needed?
- The Cloud Feedback Model Intercomparison Project Observation Simulator Package (COSP) and its status
- What is now possible with simulators
- Examples of science enabled by simulators
- Summary and future plans



Why “satellite simulators” for clouds?

- There are significant differences between how a climate model represents clouds and what satellites see
  - scale of model grids (~100 km) vs. satellite pixels (~1 km)
  - model variables and satellite observables

- We need a way to interpret a model that minimizes the effects of different definitions and observational limitations in order that differences between models and observations are more likely due to model problems rather than satellite artifacts

- The **“simulator”** is a piece of diagnostic code that converts model variables into pseudo-satellite observations (retrieval quantities and instrument signals)
  - A simulator facilitates wider and better use of satellite observations by the climate modeling community

What is in a satellite simulator?

- Satellite simulator contains in code the things needed to "simulate" the observational process:
  - *What would a satellite see if the atmosphere had the clouds of a climate model?*

- A satellite simulator contains
  - A "down-scaler" from large-scale to satellite-scale
  - Simplified forward models (e.g. *dBZ*, β_e, T_b) & retrieval algorithms

- Simulators address these problems
  - Cloud overlap (column-integrated τ and cloud-top pressure p_{ct} of the high cloud in the column)
  - Detection thresholds (τ >= 0.3, *dBZ* > -25, *SR* > 5)
  - Retrieval characteristics (p_{ct} from T_b (ISCCP), CO_2 slicing (MODIS) or stereo-imaging (MISR))

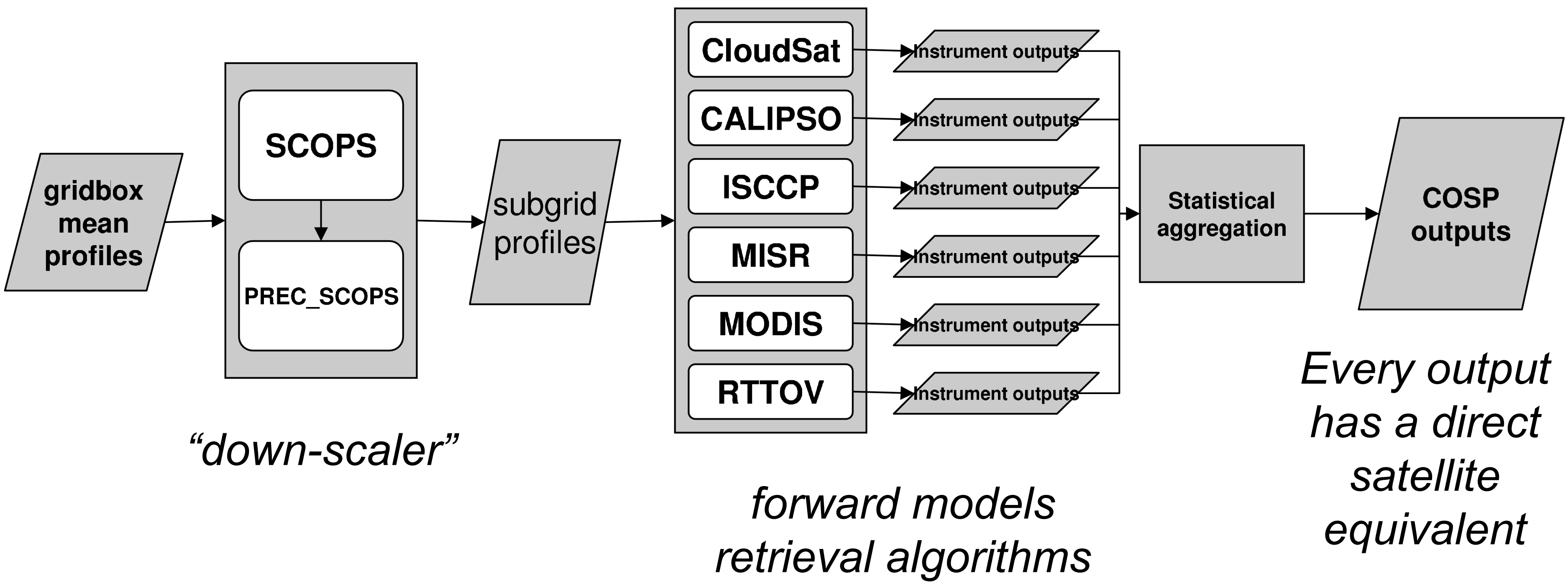
Simulator considerations

- A simulator needs to be practical
  - It needs to fast enough to be included in climate models while they're integrating
  - Thus simulators do not include everything about the observational process (e.g. satellite view angle effects on cloud detection, calibration coefficients of different satellites)

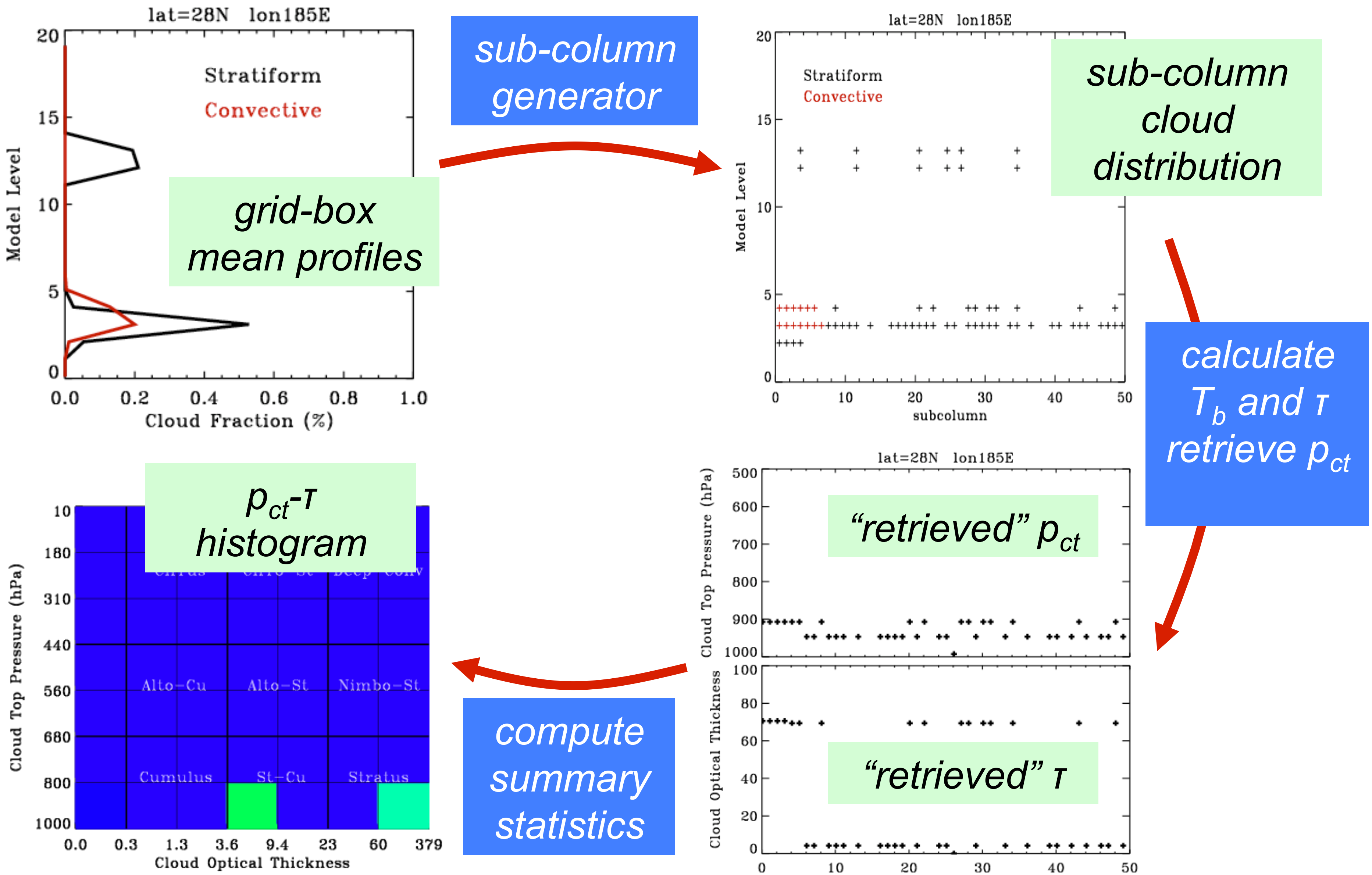
  The simulator must take care of first-order issues with a simplified calculation

- Simulators do not solve all difficulties in comparing models to observations
  - As an example, simulators can't deal with satellite artifacts that result from partially cloudy satellite pixels
  - Simulators are a significant step in the right direction, but they don't preclude other ways of comparing observations and models

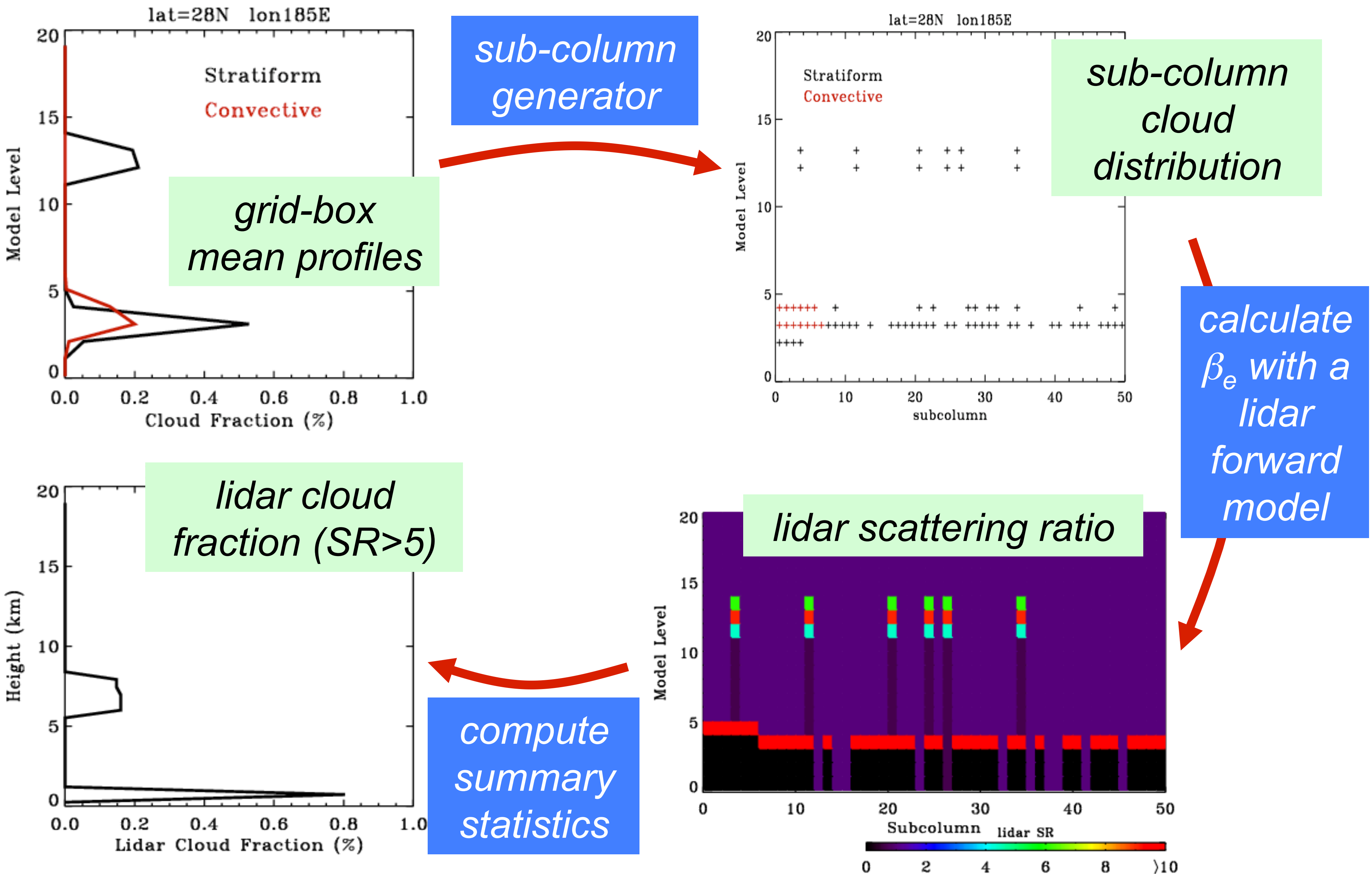
COSP Flow Chart



Simulator example (ISCCP)

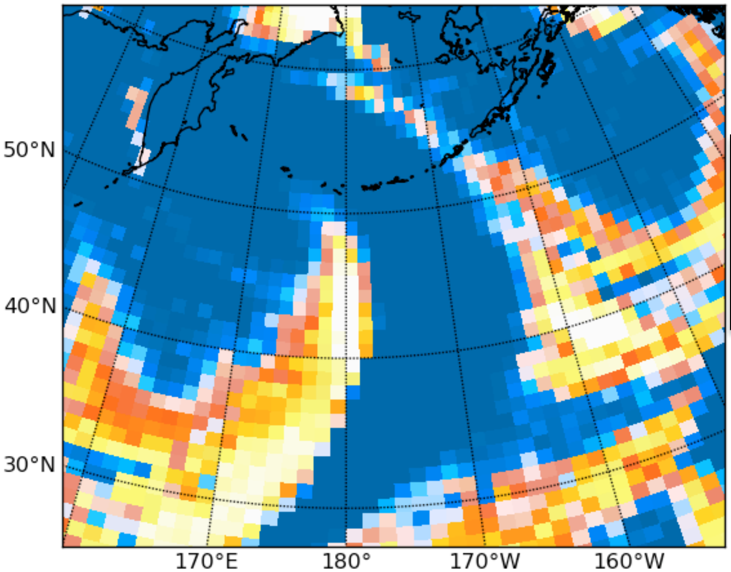


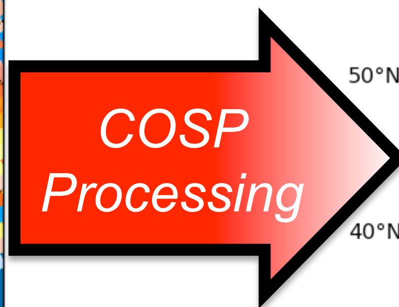
Simulator example (Calipso)



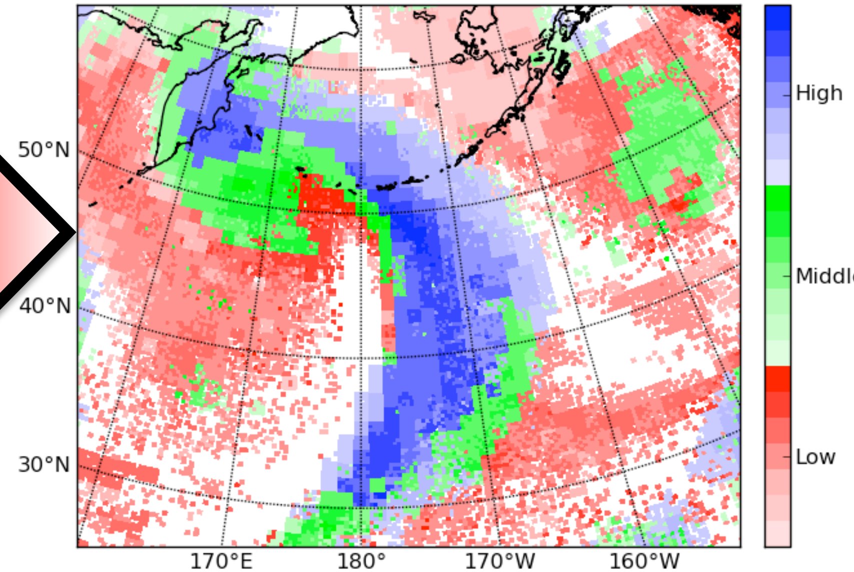
End Result

Climate Model Clouds





Pseudo-Satellite Observations



Actual Satellite Observations

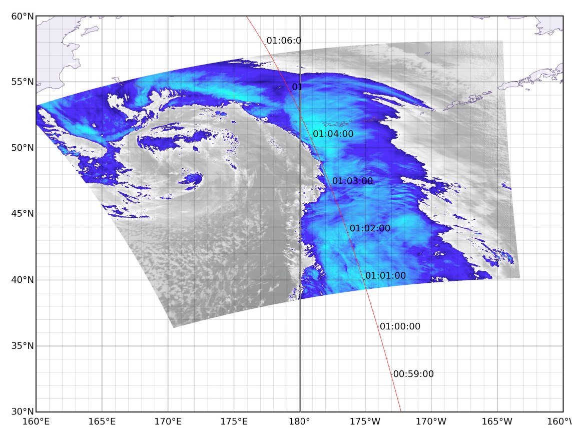


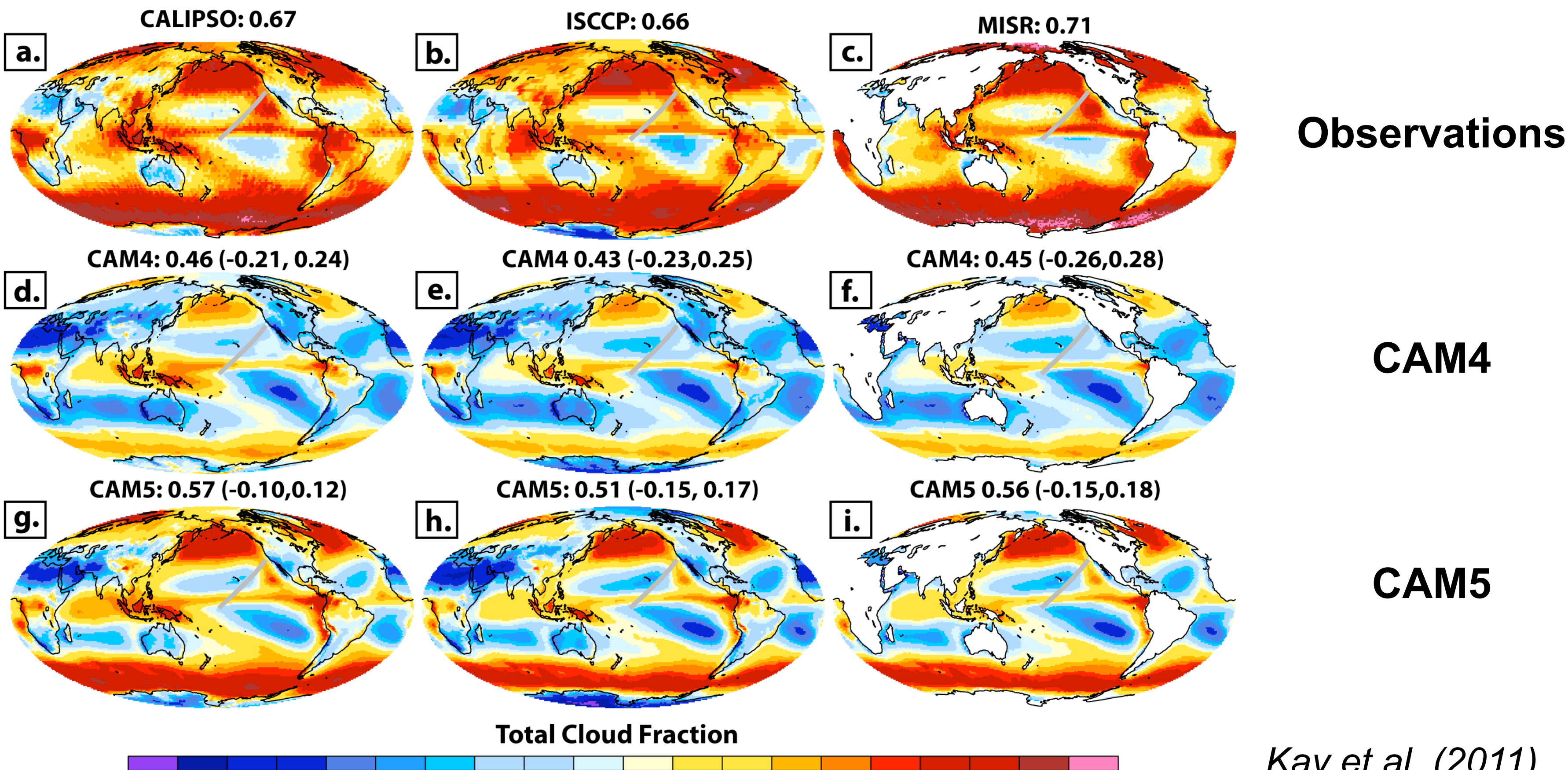
Figure credit: Jim Boyle (LLNL), Alejandro Bodas-Salcedo (UKMO) and Stephen Klein (LLNL)

COSP Status

- About 5 years ago, the CFMIP community banded together to form community software package of simulators for the climate modeling community
- COSP code is freely available http://code.google.com/p/cfmip-obs-sim/ and is governed by a project management committee
- COSP has simulators for 5 observational products
  - ISCCP, MISR, MODIS, CloudSat, Calipso
- All major climate models use it (CAWCR, CNRM, BCC, IAP, CCCMa, GFDL, KNMI, LMD, MPI, NASA/GISS, NCAR, NIES, MRI, UKMO, JAMSTEC, etc.)
  - Used in Japanese 14 km NICAM
  - Most have put the code in-line to their model
- A matching set of observations for each simulator has been specially prepared in ESG compatible format and is available from http://climserv.ipsl.polytechnique.fr/cfmip-obs.html

What is now possible with COSP

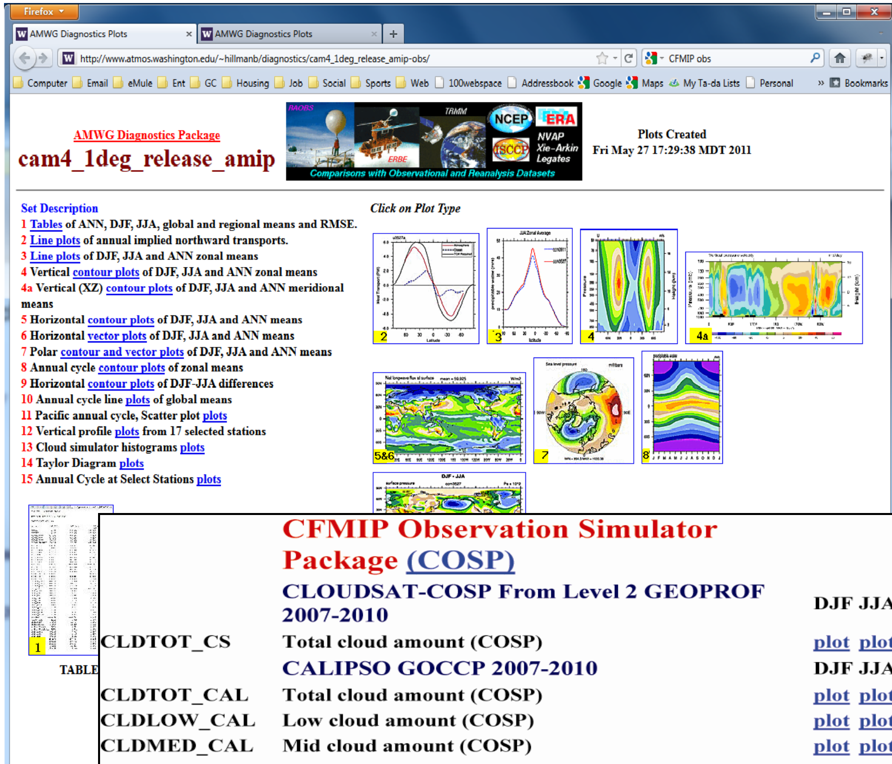
Comparison to multiple satellites



Kay et al. (2011)

- What model strengths and problems are robust
- A comparison is meaningful when total cloud fraction is well-defined

Diagnostics for model development



CFMIP Observation Simulator Package (COSP)

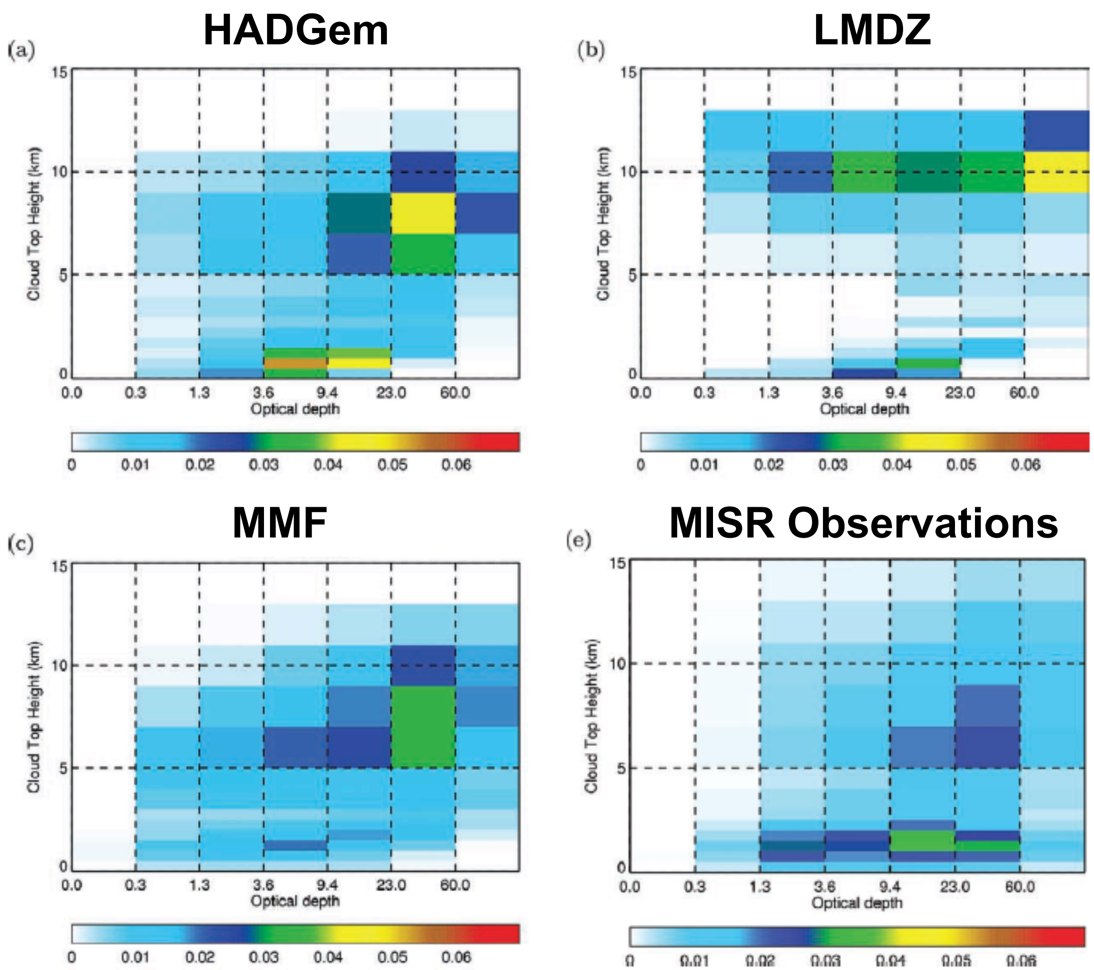
	CLOUDSAT-COSP From Level 2 GEOPROF 2007-2010	DJF	JJA	ANN
CLDTOT_CS	Total cloud amount (COSP)	plot	plot	plot
	CALIPSO GOCCP 2007-2010	DJF	JJA	ANN
CLDTOT_CAL	Total cloud amount (COSP)	plot	plot	plot
CLDLOW_CAL	Low cloud amount (COSP)	plot	plot	plot
CLDMED_CAL	Mid cloud amount (COSP)	plot	plot	plot
CLDHGH_CAL	High cloud amount (COSP)	plot	plot	plot
	CLOUDSAT+CALIOP 2B GEOPROF Sep2006-Nov2010	DJF	JJA	ANN
CLDTOT_CALCS	Total cloud amount (COSP)	plot	plot	plot
	ISCCP-COSP From D1 Daytime Jul1983-Sep2008	DJF	JJA	ANN
CLDTOT_ISCCP	Total cloud amount (COSP)	plot	plot	plot
	MISR L3 CTH-OD V5 Mar2000-Nov2009	DJF	JJA	ANN
CLDTOT_MISR	Total cloud amount (COSP)	plot	plot	plot
	MODIS-COSP 2003-2010	DJF	JJA	ANN
CLIMODIS	Total ice cloud amount (COSP)	plot	plot	plot
CLWMODIS	Low liquid cloud amount (COSP)	plot	plot	plot
CLTMODIS	Total cloud amount (COSP)	plot	plot	plot

Work of Ben Hillman (UW) and Jen Kay (NCAR)

- Automatic diagnostic package generates hundred of plots to compare COSP output with satellite data
- This puts model-satellite comparisons at a model developer’s finger tips

Standardized comparison between models

MISR cloud-top height – τ histograms (40N-60N, 160E-125W)

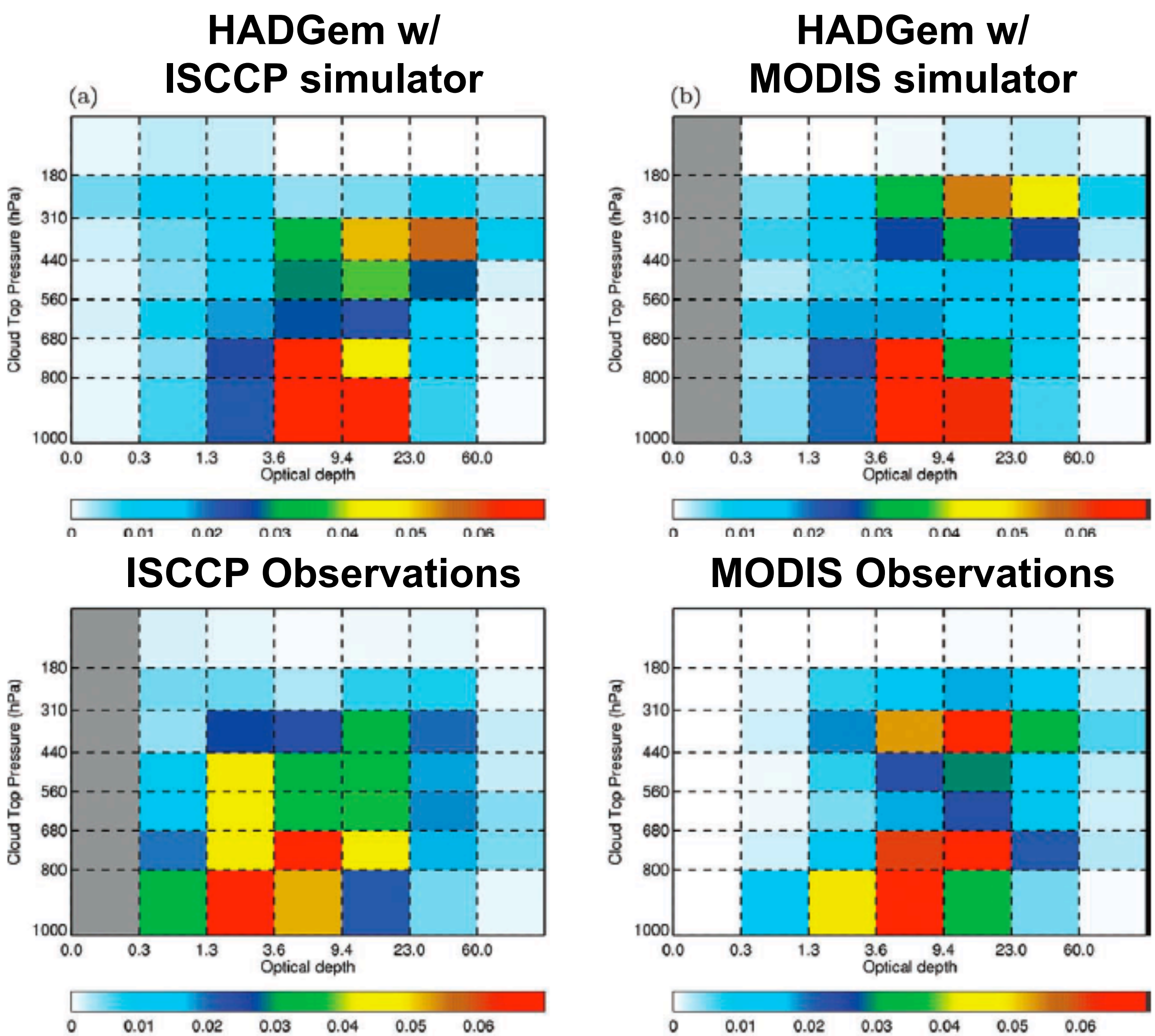


- In the past, it was difficult to compare models to each other due to their differing ways of parameterizing clouds
- A simulator greatly facilitates model intercomparison!

Bodas-Salcedo et al. (2011)

Simulators can mimic some of the differences between satellites

$p_{ct} - \tau$ histograms (40S-60S, 180-105W)



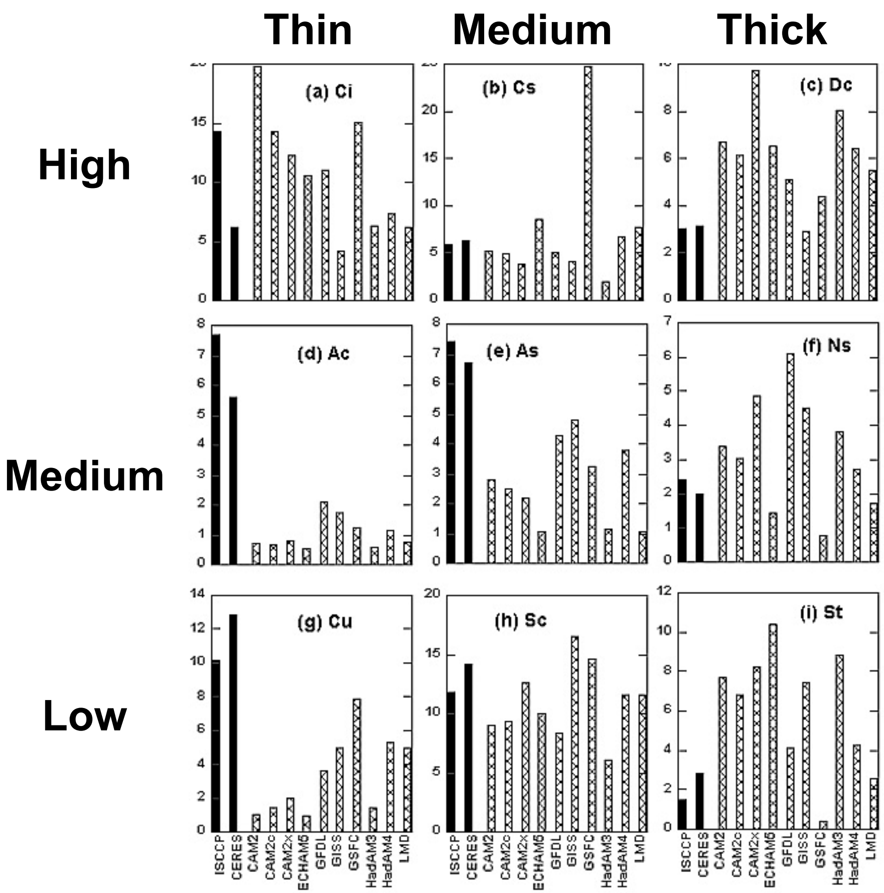
- If models produce high thin over thick low clouds, the ISCCP simulator will produce a middle level cloud and MODIS simulator will produce a high-topped cloud
- Differences between ISCCP and MISR are an estimate of multi-layer cloud

Bodas-Salcedo et al. (2011)

(Marchand et al. 2010)

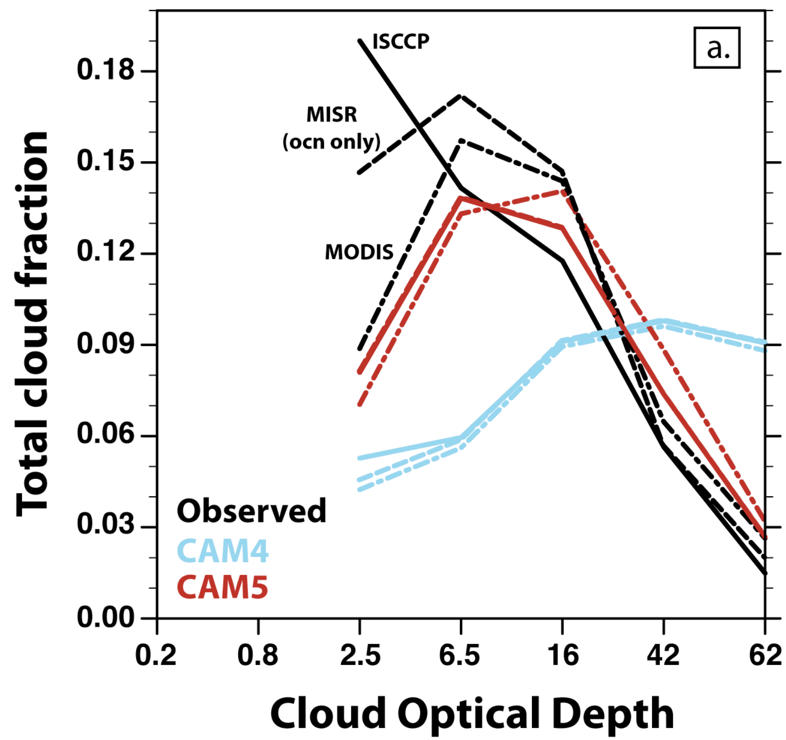
Science enabled by COSP

Models have too many optically thick clouds



Zhang et al. (2005)

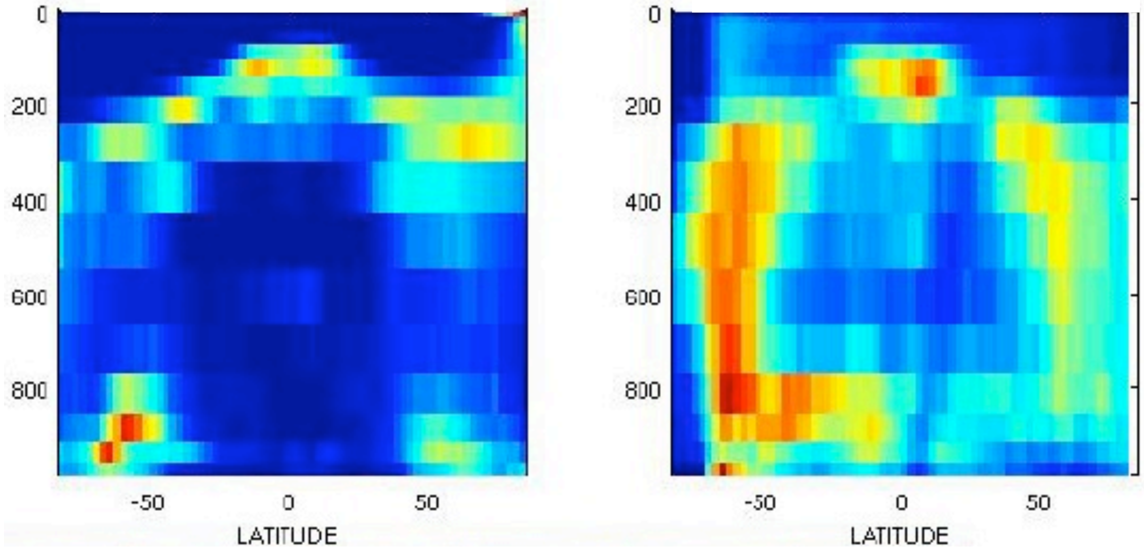
- But there are signs of improvement



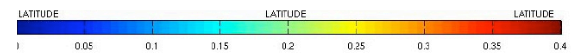
Kay et al. (2011)

Models have too few middle level cloud

LMD Simulator Cloud Fraction | **Calipso Cloud Fraction**

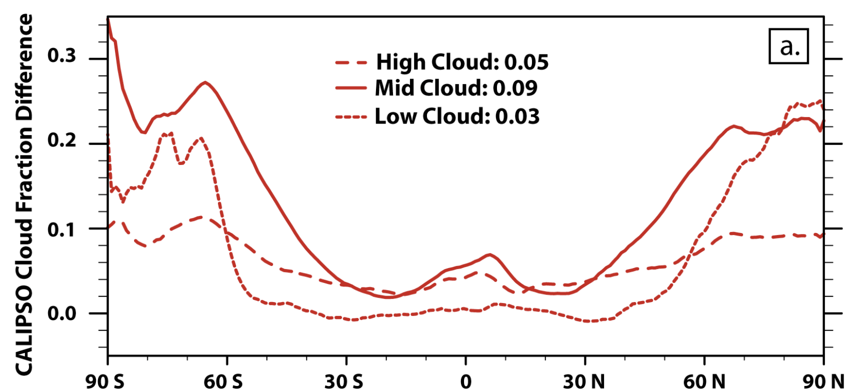


Chepfer et al. (2008)



	Middle-level cloud fraction
Calipso observations	0.18
CAM5 ignoring snow	0.06
CAM5 counting snow	0.15

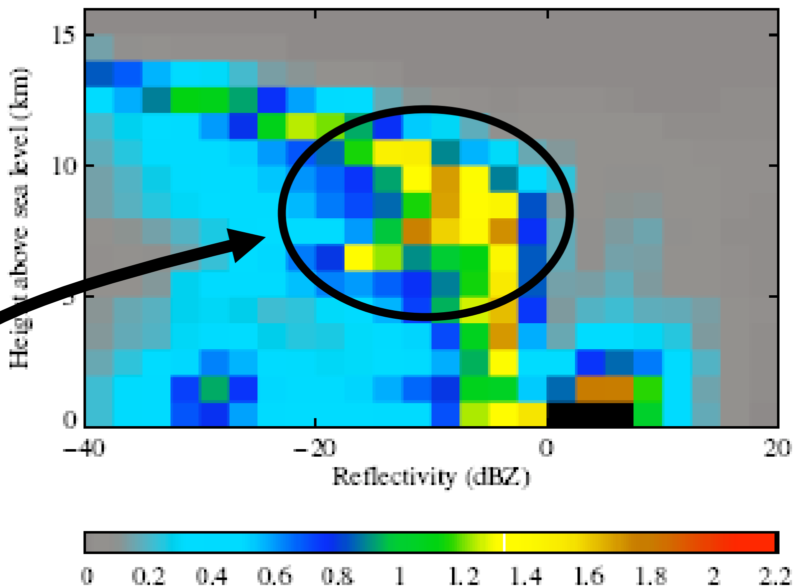
- CAM5 now computes the radiative properties of snow; treating this in the simulator dramatically increases the amount of middle level cloud



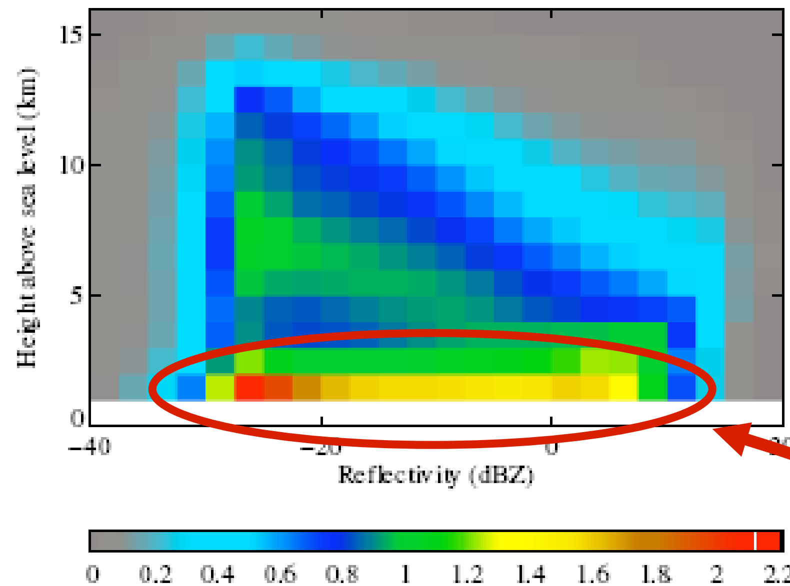
Kay et al. (2011)

Models precipitate too frequently

UKMO Simulator



CloudSat



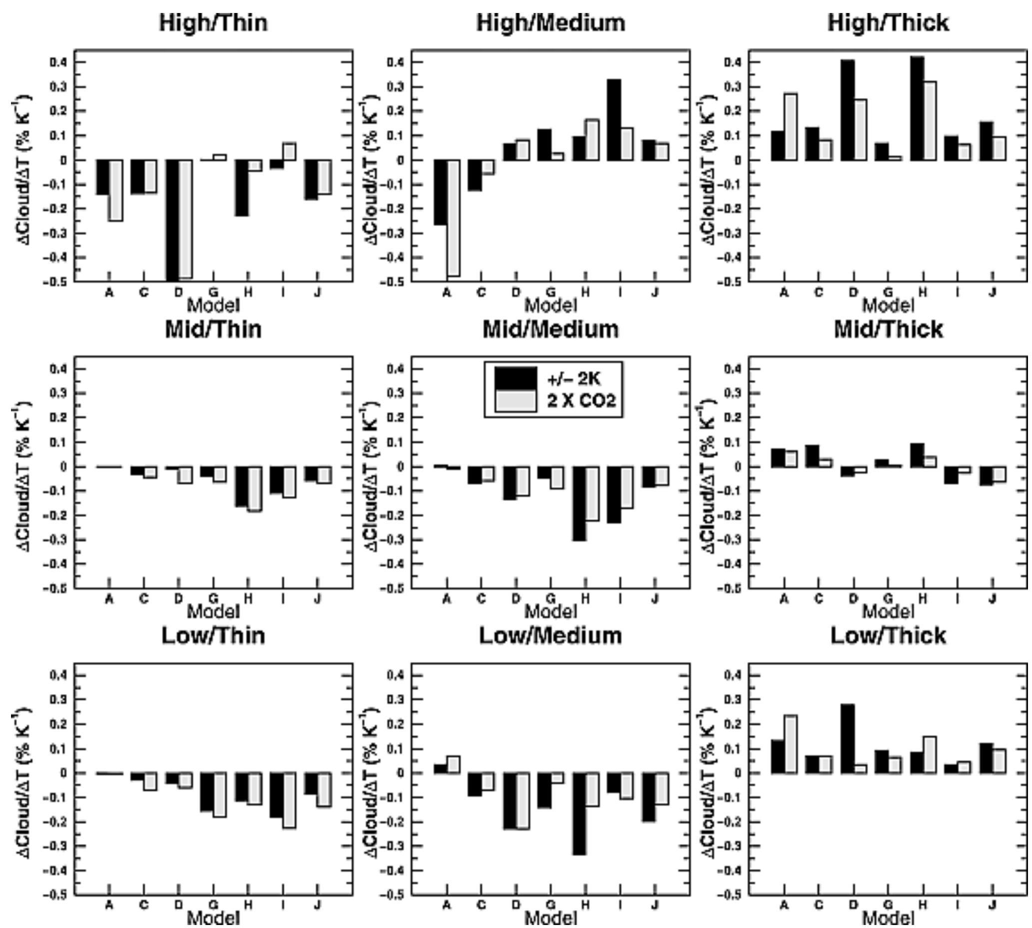
Model ice-snow is too reflective and dBZ distribution too narrow

Bodas-Salcedo et al. (2008): Global mean reflectivity-height histogram

Continuous distribution between cloud (< -15 dBZ) and drizzle or rain (> -15 dBZ) unlike model

Diagnosing cloud feedbacks to climate change

- The ISCCP simulator has allowed us to diagnose how climate change alters clouds
- Climate change leads to an increase in optical thickness
- Climate change increases the altitude of high clouds and decreases the amount of low and middle level cloud



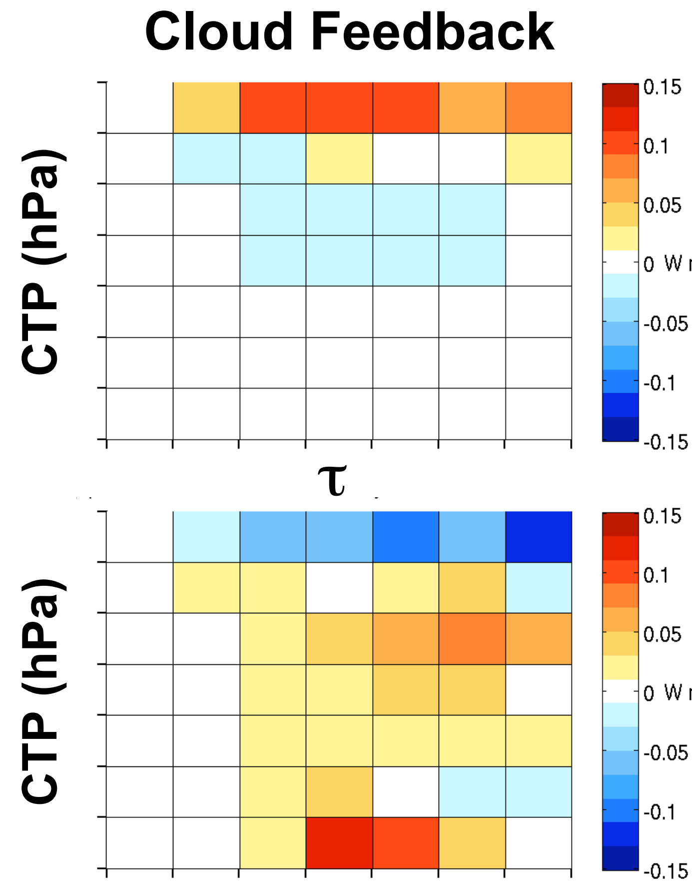
Ringer et al. (2006)

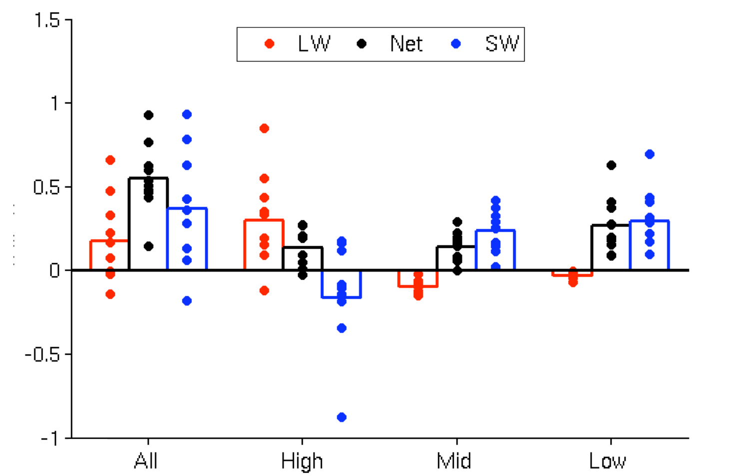
Diagnosing cloud feedbacks

- With a radiative transfer code applied to the ISCCP simulator output (“cloud kernels”), one can compute how much each cloud type contributes to cloud feedback in the climate models as well as the relative importance of changes in cloud amount, altitude, and optical depth
- This wouldn’t have been possible without the ISCCP simulator

LW
0.27
$Wm^{-2}K^{-1}$

SW
0.44
$Wm^{-2}K^{-1}$





Zelinka et al. (2011a, 2011b)

Summary and future plans

- The adoption of satellite simulators for clouds by the climate modeling community has greatly facilitated
  - better and wider use of satellite data by climate modelers
  - credible inter-model comparisons of cloud properties and feedbacks

- What's coming up for satellite simulators?
  - **Simulator improvements:** aerosols, precipitation, better sub-grid distributions, improved use by CRMs/LES models
  - **CMIP5/CFMIP2:** a much larger set of experiments and simulators will be collected facilitating a much more detailed analysis of clouds and their feedbacks in climate models

- You have opportunities to contribute
  - Evaluation of model output
  - Contributing new diagnostics or simulator capabilities

Questions?

Extra slides

COSP output variable list

Table 1. List of diagnostics from the COSP version 1.3.

Simulator	Output diagnostics
CALIPSO	Lidar total backscatter (532 nm)
	Lidar molecular backscatter
	Height–scattering ratio histograms
	Low-level cloud fraction (CTP > 680 hPa)
	Midlevel cloud fraction (440 < CTP < 680 hPa)
	High-level cloud fraction (CTP < 440 hPa)
	3D cloud fraction
	Total cloud fraction
CloudSat	Radar reflectivity
	Height–reflectivity histograms
ISCCP	Mean cloud albedo
	Mean CTP
	Mean 10.5-μm T_B
	Mean clear-sky 10.5-μm T_B
	Mean cloud optical depth
	CTP in each subcolumn
	Cloud optical depth in each subcolumn
	CTP–τ histograms
	Total cloud fraction
MISR	CTH–τ histograms
MODIS	Total cloud fraction
	Liquid cloud fraction
	Ice cloud fraction
	High-level cloud fraction
	Midlevel cloud fraction
	Low-level cloud fraction
	Total cloud optical thickness
	Liquid cloud optical thickness
	Ice cloud optical thickness
	Total cloud optical thickness [Log_{10}(mean)]
	Liquid cloud optical thickness [Log_{10}(mean)]
	Ice cloud optical thickness [Log_{10}(mean)]
	Liquid cloud particle size
	Ice cloud particle size
	CTP-τ histograms
	Cloud liquid water path
	Cloud ice water path
	Cloud area fraction
PARASOL	Monodirectional reflectance
RTTOV	Clear-sky T_B
Combined	CALIPSO cloud fraction undetected by *CloudSat*
	Total cloud fraction from *CloudSat* and CALIPSO